Geoacoustic and Tomographic Inversion of Haro Strait Data

A. Tolstoy
1538 Hampton Hill Circle, McLean VA 22101
phone: (703) 760-0881 email: atolstoy@ieee.org

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LONG TERM GOALS

The primary long term objective of this project is to provide a real-time, wide area technique in shallow water for the estimation of volumetric geoacoustic parameters. These parameters are vital inputs for SONAR models (and subsequent signal processing and target localization methods) and include: geometric values (such as source location, array element location, and water depths) as well as bottom properties (such as sediment layer thicknesses, sound-speed profiles, densities, and attenuations).

This wide area estimation would be made via multiple air-deployed receiver arrays and multiple broadband air-deployed low frequency sources.

OBJECTIVES

The objectives of this first year's work included:

- the incorporation of the RAMGEO (Collins, '94) range-dependent PE propagation model into the inversion codes.

- the geometric inversion of an individual Haro Strait nw014 (data) slice (and the nw024, sw029 paths) to determine likely source ranges and depths, array element localizations, water depths assuming a *flat* path and *two* reflections (a 4-dimensional set of possible values was found plus possible array shapes). Different Haro Strait slice inversion efforts have also been made by Jaschke and Chapman ('99), Corré and N.R. Chapman ('01), and Pignot and Chapman ('01).

- the geometric inversion of an individual Haro Strait nw014 (data) range-dependent slice (and the nw015 path) to determine likely source ranges and depths, array element localizations, water depths at the source and water depths at the array assuming a *sloping* path and *four* reflections (a reduced 5-dimensional set of possible values was found plus array shapes).

- the estimation of geometric parameters as well as bottom surficial sound-speeds for the simulated and measured nw014 (data) path assuming a sloping path, four reflections, and using only the top four array phones (a 6-dimensional set of possible values was found assuming a vertical array).

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- the beginning of broadband (4 frequencies) inversion investigation in order to try for the *unique* estimation of geoacoustic parameters for the nw014 and other Haro St. range-dependent paths.

- ground work for a full tomographic inversion (see Tolstoy, '94) of Haro St. data.

APPROACH

First, the approach employed here involved the estimation of geometric parameters (source range and depth, array depth and shape, water depths) via the examination of the time domain signal (see also Michalopoulou and Ma, '05). Discrete data arrivals were compared to ray theoretic reflections computed by means of geometric considerations. This development is described in Tolstoy ('06a and '06b). This led to a subset of possible solutions for nw014 (as well as for a few other paths). No uniqueness was possible since many thousands of scenarios, e.g., source ranges, array configurations, etc., give *identical* arrival structures.

While the consideration of more time domain data (four rather than just two reflections), more phones, and a sloping bottom reduced the subset of possible solutions, i.e., matches to the time domain data, even this was not enough to give uniqueness for a solution. We can see in Fig. 1 wonderful agreement between one of the simulated scenarios (via time domain RAMGEO from Collins) and the measured data. There were thousands of such sets producing such agreement with the data. To try to reduce the sets, we next considered matched field processing (mfp). Consider the *simulated* data set of Fig. 1. For this inversion we allowed for only the top four phones -- this was to reduce the run times as well as to limit array shapes to simpler forms, e.g., vertical.

In particular, we began with an FFT of the simulated nw014 data to yield complex pressure fields along the data array at a variety of frequencies. Since both the measured and simulated data are all given for 1024 points at a sample rate of 1755 per sec, we have 0.583 sec of data. Next, we zero-filled before and after the "data" to arrive at 2048 points for 1.166 sec of data resulting in a frequency sampling of 0.858 Hz within our intended bounds of [200,600] Hz. As an example, for the simulated data (generated every Hz from 200 to 800 Hz) we considered FFT frequencies of 488.3, 490.0, 496.0, 496.85 Hz (close to the discrete frequencies).

After the FFTs, we considered mfp for these high frequencies (around 500 Hz) in order to *refine* the geometric parameters as well as to *estimate* the surficial sound-speed c_1 as suggested by SUB-RIGS (Tolstoy, '98, '04). The computations for these parameters were done by comparing the complex "data" pressure field versus a simulated complex field (also generated by RAMGEO) via mfp at a single frequency, e.g., 490.0 Hz. The steps involved:

- *a crude search* of important parameters--we immediately eliminated those parameters not allowed by the geometric matches in the time domain (this improved computational efficiency enormously). Hence, we are looking for large values of mfp which match the allowed geometry. In particular, for nw014 we consider all scenarios for which the source range is in [225, 265] m in 2 m increments, source depth is in [63, 70] m in 1 m increments, the water depth at the source is D_1 in [190, 200] m in 1 m increments, the water depth at the array is D_2 in [200, 210] m in 1 m increments, and the sound-speed at the surface of the bottom c_1 is in [2000, 2500] m/s in 100 m/s increments. Without the elimination by

geometric sets we would have nearly 122,000 cases to consider, i.e., lots of CPU time at 10 cases per s.

- *plots* of the resultant large mfp values (as seen in Fig. 2) as a function of source range and depth as well as array depth. If we knew the array depth (top phone at z_{ph1}, then we could eliminate many competing candidates. However, the array depths are not known. We note that there are many parameter sets (multiples can be represented by a single circle (varying water depths D_1, D_2), and there are many circles) which allow for geometric matches as well as large mfp values.

- a plot of the (normalized) *distributions* of various parameter values (such as source range in Fig. 3) where we know the "true" value of 248 m for the simulated "data" as indicated by vertical line. This is a distribution (at a single frequency, e.g., 490.0 Hz) for those ranges corresponding to mfp ≥ 0.90 and for all candidate array depths, water depths, source depths, and c_1. We cannot simply accept the peak range value here (we see a clear bias in this instance). Moreover, we cannot perform this step at multiple frequencies and look for common ground since the search is too crude and may not include a solution at all.

- *refined searches* of parameters suggested by the distributions. These refined searches (for the simulated data these were: source range in [243, 259] m in 1 m increments, source depth in [64, 67] m in 1 m increments, D_1 in [190,197] m in 1 m increments, D_2 in [200, 207] m in 1 m increments, c_1 in [2100, 2600] m/s in 100 m/s increments) were done at four multiple frequencies resulting in new distributions where all the frequencies had to have large mfp values at the *same* parameter values in order for the values to be "solution" candidates. Thus, the solution candidates will satisfy the geometric (time domain arrival) considerations and have large mfp values, e.g., mfp ≥ 0.95, for all (four high) frequencies.

After the final refined search we successfully found a nearly unique "solution" for the simulated data. To recap: this approach required the geometric elimination of many parameters, followed by the FFT of the "data", followed by a crude mfp search to compute a distribution of possible solutions, followed by refined mfp searches at four similar frequencies concluding with the elimination of parameters which do not simultaneously have mfp ≥ 0.95 at all four frequencies. Next, we will apply this approach to the nw014 *data.*

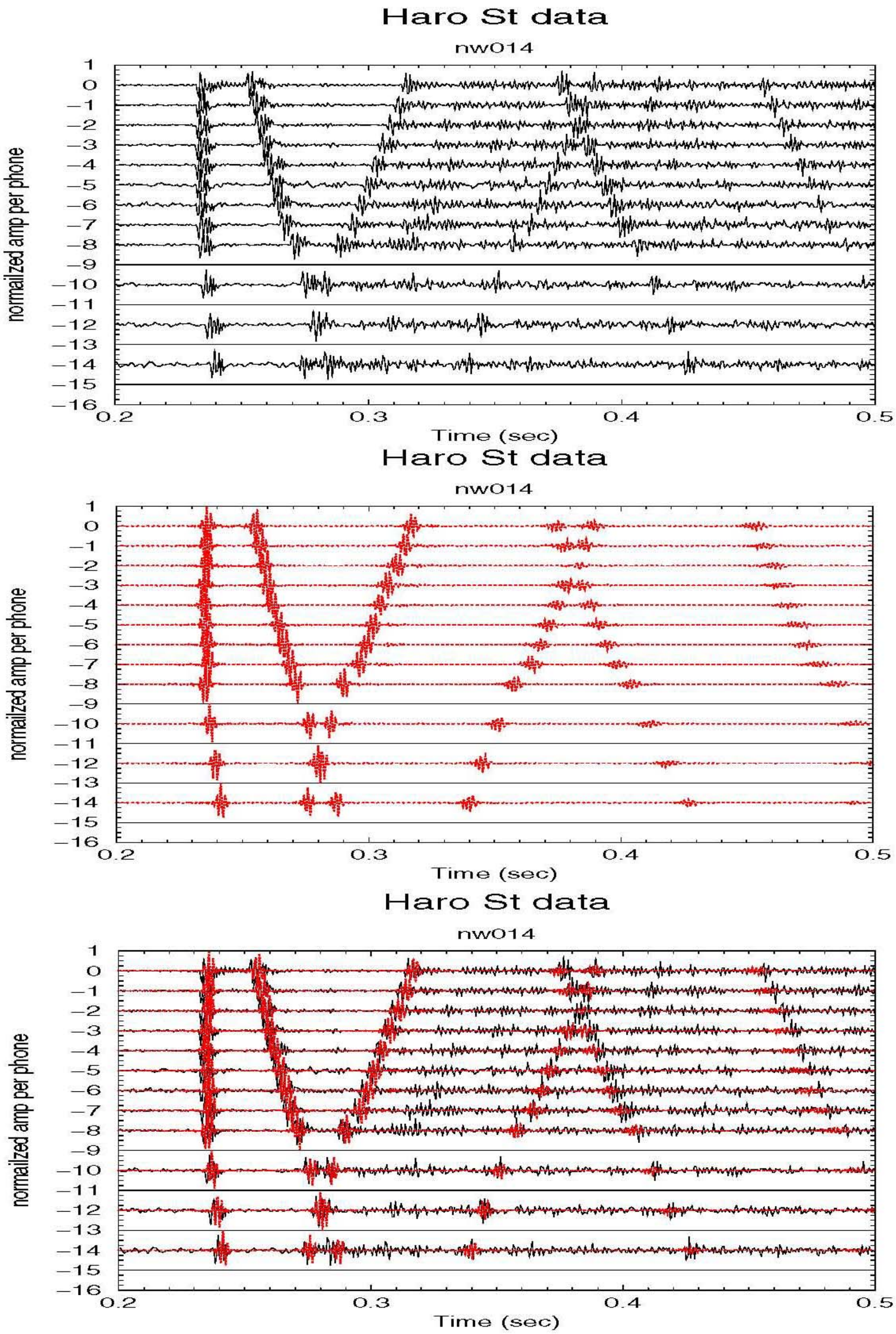

Fig 1 Comparison of nw014 Haro Strait data and simulated data where the simulated data parameters have been estimated by means of time domain estimation of geometric parameters (Tolstoy, '06b). We have assumed a sloping bottom and used four reflections for the inversion. The simulated data represent only one of thousands of parameter sets which fit the time domain data.

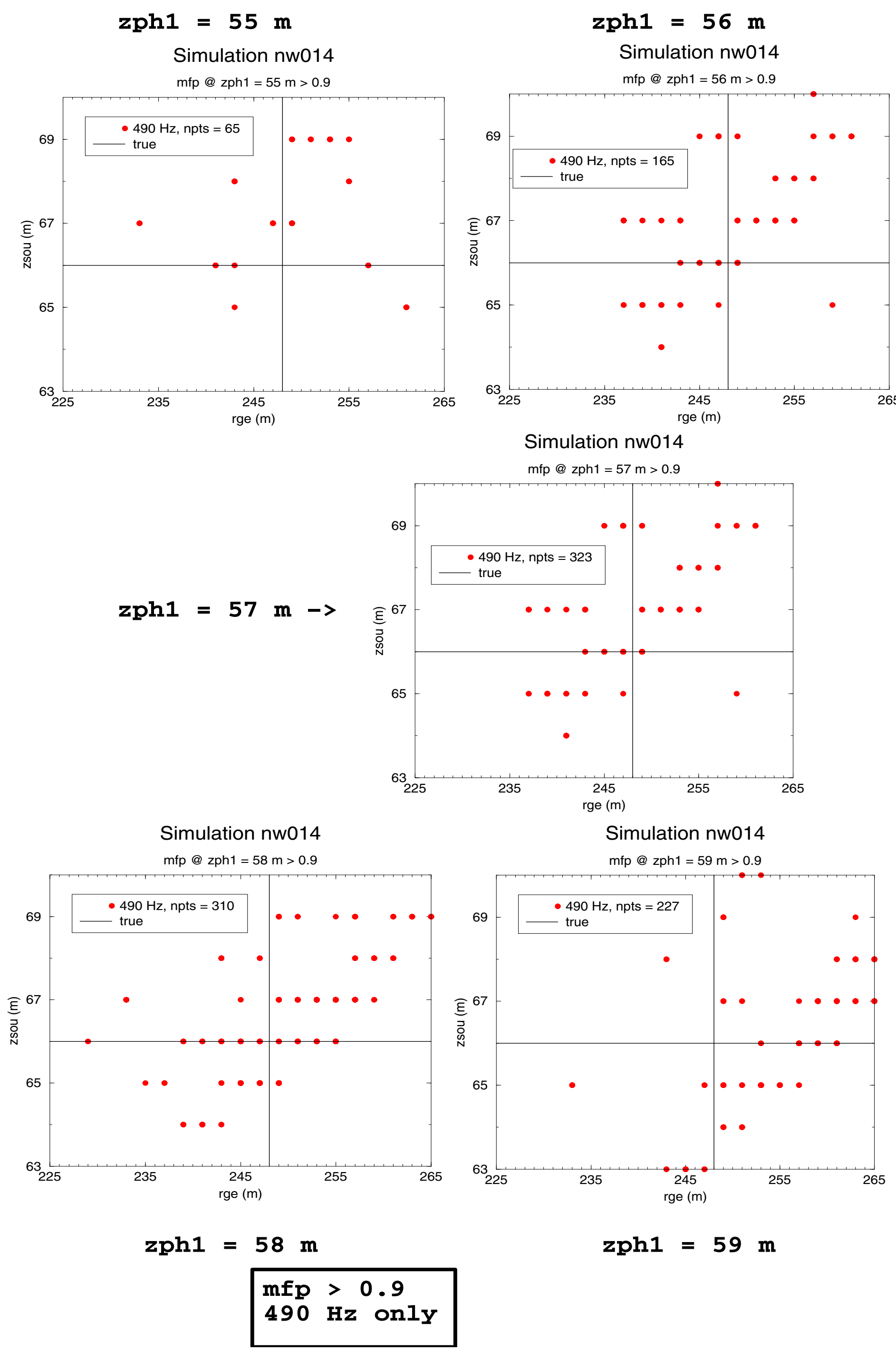

Fig 2 In this figure after FFTing the simulated "data" of Fig. 1 we see candidate source locations (ranges and depths) indicated by the filled circles at which the mfp correlation (comparison of "data" and PE simulations at 490 Hz) is greater than 0.9. We see numerous possible array depths (55, 56, 57, 58, 59 m) and numerous source locations (ranges and depths) which have excellent mfp correlation values. The "true" source range and depth are indicated by the cross hairs at rge = 248 m, zsou = 66 m, and the top phone depth $z_{ph}1$ at 56 m. We clearly see that for this single frequency (490 Hz) we cannot hope to uniquely determine the geometric or geoacoustic properties for nw014 using only the domain geometry.

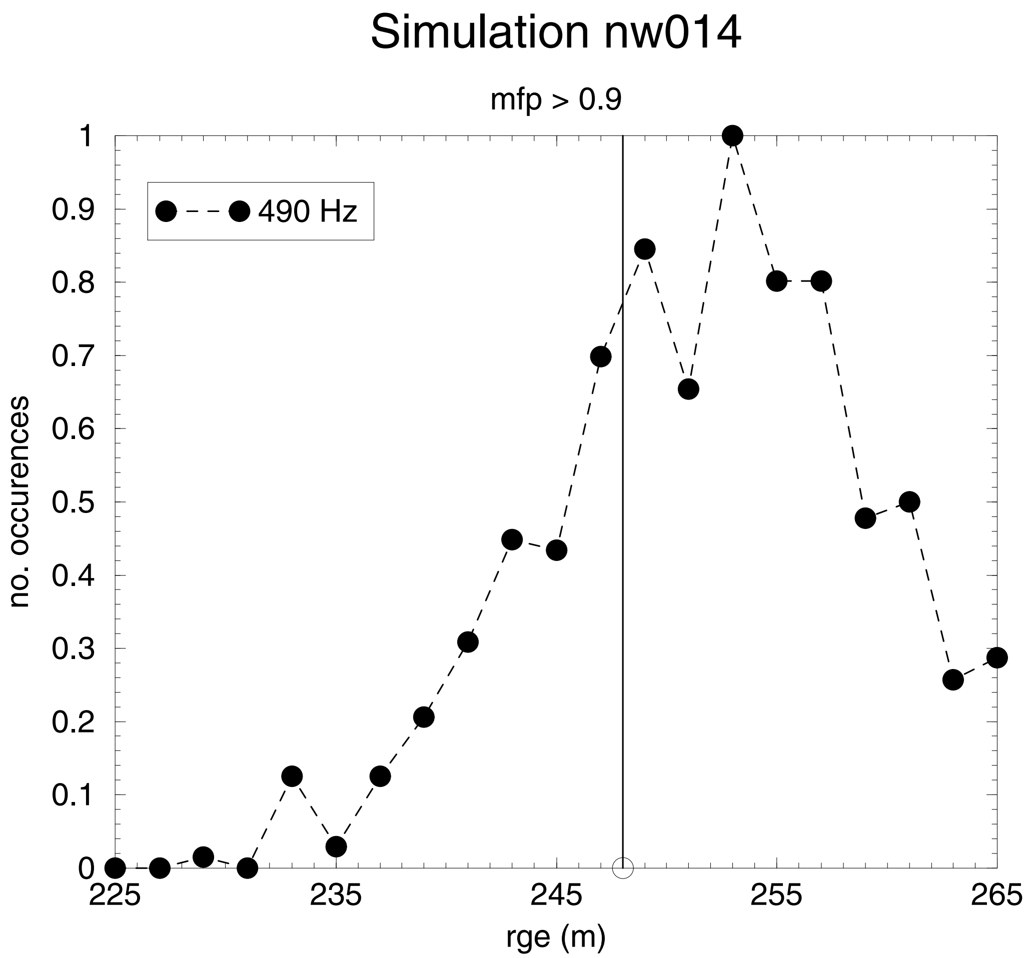

Fig 3 This plot shows a (normalized) distribution of source ranges for the simulated nw014 data of Fig. 1 with an mfp ≥ 0.9 at 490.0 Hz. This plot can also be interpreted as a projection of Fig. 2 (combining all the candidate solution sets with large mfp values into one figure). We recall that these values were found after a crude search through parameter space and are subsequently used to refine searches around the peak parameter values, e.g., refined range next in [243, 259].

WORK COMPLETED

Recent work (FY06) has resulted in:

- The incorporation of RAMGEO into the inversion software.

- The development and demonstration on a single slice of (nw014) Haro Strait data of a method to find candidate source-array *geometries* based on the time domain data arrivals, i.e., by means of four boundary reflections assuming a sloping bottom and up to 16 phones.

- The development and demonstration on a single slice of (nw014) simulated Haro Strait "data" of a method using SUB-RIGS on the reduced (by the geometric search) sets of candidate

parameters to iteratively *refine* searches at *multiple frequencies* at a single slice of (nw014) Haro Strait data until a nearly unique "solution" can be found.

RESULTS

This work was developed and demonstrated on Haro Strait data and incorporates the use of boundary reflections and time domain arrivals to restrict candidate parameter solution sets. While the "true" source range and depth, water depths at the source and array, and array configuration cannot be uniquely determined by means of the geometric considerations alone, these efforts significantly reduce the CPU search times needed for further inversion efforts. Additionally, the SUB-RIGS inversion method has been successfully applied and iteratively demonstrated on simulated nw014 "data" to finally arrive at a nearly unique "solution".

IMPACT/APPLICATION

This technique is likely to influence array technology, multiple array deployment, and the selection of propagation models used by the fleet for target detection, localization, and geoacoustic inversion. The estimation of true 3-D geoacoustic properties (see Tolstoy, '94; '98; '04) will be extremely important for the detection and localization of targets such as subs as well as of buried targets such as mines.

RELATED PROJECTS

Investigations in the area of geoacoustic inversions are being conducted by the Canadians (N. Chapman et al. investigating the Haro Strait data; G. Heard et al.), Europeans (R. Hamson and M. Ainslie of Great Britain; S. Jesus of Portugal; D. Simons and M. Snellen of The Netherlands; Y. Stephan et al. of France; M. Taroudakis and M. Markaki of Greece; V. Westerlin of Sweden), and Asians (P. Ratilal et al. of Singapore; R. Zhang et al. of China). Moreover, geometric considerations are being examined by E. Michalopoulou at NJIT as well as by Skarsoulis et al. (Greece).

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